C Language Constructs for Parallel Programming

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Cilk Plus

Parallel tasks
- Easy to learn: 3 keywords
- Tasks, not threads
- Load balancing

Hyper Objects
- Mitigate data races on non-local variables

Array notations
- Data-parallel array operations
- Targets SIMD

Elemental Functions
- Data-parallel function mapping

SIMD Loops
- Vectorization annotation for loops
- Single threaded vector parallelism
int tree_walk(node *nodep) {
    int a = 0, b = 0;
    if (nodep->left)
        a = _Cilk_spawn tree_walk(nodep->left);
    if (nodep->right)
        b = _Cilk_spawn tree_walk(nodep->right);
    int c = f(nodep->value);
    _Cilk_sync;
    return a + b + c;
}
"Serialization" of Tree-walk Example

```c
int tree_walk(node *n)
{
    int a = 0, b = 0;
    if (n->left)
        a = _Cilk_spawn tree_walk(n->left);
    if (n->right)
        b = _Cilk_spawn tree_walk(n->right);
    int c = f(n->value);
    _Cilk_sync;
    return a + b + c;
}
```
Example of keyword vs. pragma

X = f1(a,b) + _Cilk_spawn f2(c,d);

X = _Cilk_spawn f1(a,b) + f2(c,d);

• The above is currently disallow in Cilk Plus
  – But this is not a necessary restriction
  – Can be allowed

• The pragmas are separate from the C expression

• Hard to point out an exact point within a sub expression
cilk_for Loop

cilk_for (int i = start; i < finish; i += stride)
  { /* Body of loop uses i */ }
f();

The loops has to be a countable loop
Multiple linear increment allowed

Loop invariant.

Iterations can execute in parallel.
All iterations complete before f() execute
Reducer Hyperobjects

• “Traditional” reduction on a parallel for loop:
  long a[sz];
  reducer_opadd<int> sum = 0;
  cilk_for (int i = 0; i < sz; ++i)
    sum += a[i];

• Generalized reduction for any code executing in parallel:
  reducer_opadd<int> sum = 0;
  void sum_tree(node* nodep) {
    if (nodep->left) cilk_spawn sum_tree(nodep->left);
    if (nodep->right) cilk_spawn sum_tree(nodep->right);
    sum += nodep->value;
  }
Array Notation Example

• Serial Example
float dot_product(unsigned int sz,
    float A[], float B[]) {
    float dp=0.0f;
    for (int i=0; i<sz; i++)
        dp += A[i] * B[i];
    return dp;
}

• Array Notation Version
float dot_product(unsigned int sz,
    float A[], float B[]) {
    return __sec_reduce_add(A[0:sz] * B[0:sz]);
}
Rank and Shape

• An array section doesn't have a new kind of type
  – the type of an array section is exactly that of the analogous subscript expression.
  – Additionally, an array section has rank and shape.

• A section implicitly iterates over some elements of an array.
  – Rank is the number of levels of loop nesting (i.e. dimensions) in the iteration space.
  – Shape is a (mathematical) vector of lengths. (The rank is the same as the length of the shape vector.)
**Rank and Shape (continued)**

- The rank of an expression is determined statically. In general, the shape of a section is determined dynamically.

<table>
<thead>
<tr>
<th>Expression</th>
<th>Rank</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>a[0]</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>a[0:n]</td>
<td>1</td>
<td>n</td>
</tr>
<tr>
<td>a[0][i:10]</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>a[i:n][j:m]</td>
<td>2</td>
<td>n×m</td>
</tr>
</tbody>
</table>
Shapes have to match

- If array size is not known, both lower-bound and length must be specified
- Section ranks and lengths ("shapes") must match.
  - Scalars are OK.
    
    \[
    a[0:5] = b[0:6]; \quad // \text{No. Size mismatch.} \\
    a[0:5][0:4] = b[0:5]; \quad // \text{No. Rank mismatch.} \\
    a[0:5] = b[0:5][0:5]; \quad // \text{No. No 2D->1D} \\
    a[0:4] = 5; \quad // \text{OK. 4 elements of A filled w/ 5.} \\
    a[0:4] = b[i]; \quad // \text{OK. Fill with scalar } b[i]. \\
    a[10][0:4] = b[1:4]; \quad // \text{OK. Both are 1D sections.} \\
    b[i] = a[0:4]; \quad // \text{No. 1D } \rightarrow \text{ 0 D}
    \]
Array Notations → Vector Operations

• Selection of array elements
  – “vector” refers to a 1D array. Current implementation does not allow [:] to be overloaded, e.g., for std::vector.

```
A[:]]  // All of vector A
C[:][5]  // Column 5 of matrix C
D[0:3:2]  // Elements 0,2,4 of vector D
```

• Masked vector operations

```
if (a[:] > b[:]) {
  c[:] = d[:] * e[:];  // For elements where M contains 1
} else {
  c[:] = d[:] * 2;  // For elements where M contains 0
}
```

Array x scalar operation
Vector Loop: Order of Evaluation

```c
simd_for (int n = 0; n < N; ++n) {
    a[n] += b[n];
    c[n] += d[n];
}
```

```c
for (int n = 0; n < N; n+=2) {
    t1 = a[n];
    t2 = a[n+1]; // a[n+1] can be written
    // before c[n] and d[n] are read
    t5 = b[n];
    t6 = b[n+1];
    t1 += t5;
    t2 += t6;
    a[n] = t1;
    a[n+1] = t2;
    t3 = c[n];
    t4 = c[n+1]; // c[n+1] can only be accessed
    // after a[n]
    t5 = d[n];
    t6 = d[n+1];
    t3 += t5;
    t4 += t6;
    c[n] = t3;
    d[n] = t4;
}
```
Uniform vs. Private: Illustration

```cpp
double b = get_position();
simd_for (int i = 0; i < N; ++i) {
    double t;
    t = y[i] * cos(z[i]);
    a[i] = t / b;
}
```

- **b is uniform, t is private**
  - The proposal is mapping the concepts of a uniform and a private variables onto existing syntax

- **Assignments to b inside the loop shall result in uniform values, otherwise the behavior is undefined.**
Elemental Functions - Example

• Defining an elemental function:

```c
double option_price_call_black_scholes(
    double S, double K, double r,
    double sigma, double time) _Simd
{
    double time_sqrt = sqrt(time);
    double d1 = (log(S/K)+r*time)/(sigma*time_sqrt) +
        0.5*sigma*time_sqrt;
    double d2 = d1-(sigma*time_sqrt);
    return S*N(d1) - K*exp(-r*time)*N(d2);
}
```
void vec_add ( float *r, float *op1, float *op2, int i)
    simd (chunk (N))
    simd (uniform (r,op1, op2) , linear (i), chunk(N))
{
    r[i] = op1[i] + op2[i];
}

ssimd_for (int i = 0; i<N; ++i) {
    vec_add(a,b,c,i);
}

ssimd_for (int i = 0; i<N; ++i) {
    vec_add(a[x1[[i]]],b[x2[[i]]],c[x3[[i]]],i);
}

Two vector versions and one scalar
Call matches the version with the uniforms
Call matches the version w/o the uniforms
Optimization Notice

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Joint proposal between Cilk Plus and OpenMP

- A minimal language
- The language does not mandate a scheduling technique
- The language allows / does not disallow dynamic load balancing
- Serial semantics and serial equivalence
- Well integrated into the C language